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GENERAL FEATURES OF THE MAGNETITE ORES OF WESTERN NORTH CAROLINA AND EASTERN TENNESSEE

BY

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AVERY AND MITCHELL COUNTIES, N. C., AND NEIGHBORING PORTION OF TENNESSEE.

A line of deposits in Avery and Mitchell counties, N. C., and the adjacent part of Tennessee is described by Nitze as beginning at the mouth of Roaring Creek, 7 miles a little west of south of Cranberry, running north and northwest over Grassy Bald Ridge, turning toward the south, and continuing southwestward to the Yancey County line at Toe River. (See fig. 58.) On this line are a dozen or so small deposits that exhibit no peculiar characteristics. At the mouth of Roaring Creek, however, there is one that is worthy of notice. Here a small strip of massive dunite that is sheared in places to a chlorite-talc schist is traversed by a narrow stockwork of tiny veins of magnetic ore. The country rock is the Roan gneiss. The other deposits are evidently small and unimportant. Nearly all are in the Roan gneiss, but in some places the rock immediately associated with the ore mineral is fibrous.

OTHER DEPOSITS IN NORTH CAROLINA.

Madison and Yancey counties also contain deposits of titaniferous ores that are remarkable for their high content of titanium. Nitze[43] refers to a nearly vertical bed, from 6 to 10 feet across, at a point 6 miles north of Burnsville, on the south side of Mine Fork in Yancey County, that contains 11.90 per cent of TiO_2, and Kerr and Hanna[44] refer to another in Madison County, near Ivy Creek and near the public road between Burnsville and Asheville, that contains 37.88 per cent of TiO_2. Hanna's analysis of this ore showed 37.06 per cent of FeO and 11.03 per cent of Fe_2O_3. On the assumption that all the FeO that is not in magnetite is present in ilmenite, there is still an excess of about 2.5 per cent of TiO_2, which must be in rutile.

Deposits of titaniferous ores are indicated by float in Macon, Clay, and other mountain counties in North Carolina, but no explorations have been made in them.

OTHER DEPOSITS IN EASTERN TENNESSEE.

Three or four fairly large explorations have been made in deposits of titaniferous ore in Carter County, Tenn., but none of them have developed any considerable bodies of ore except perhaps that in Lost Cove. Mr. Hamilton, in the manuscript report already referred to, states that on the west side of the ridge between Burbank and Lost Cove magnetic float is common. At one point a pit uncovered large pieces of magnetic ore that have the purplish steel color and brilliant luster that are associated with magnetite or ilmenite mixed with rutile. Mr. Hamilton also states that though the ore is in the areas of Cranberry granite mapped by Keith, it is most intimately associated with a black gneiss.

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[43] Nitze, H. B. C., op. cit., p. 187.

[44] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, vol. 2, p. 181, Raleigh, 1888.

A partial analysis of this ore by Dr. Hinds, of the Tennesse Geological Survey, gave the following figures:

Partial analysis of ore from Lost Cove, Tenn.

Silica (SiO_2)	4.80	Titanium dioxide (TiO_2)	17.20
Alumina (Al_2O_3)	3.28	Phosphorus (P)	Tr.
Iron (Fe)	51.74		

D. F. Farrar, the present chemist of the Tennessee Survey, reports also a trace of chromic oxide. A second specimen from the same place was reported by Dr. Hinds to contain 10.50 per cent of titanium dioxide.

Float occurs also at the Cordell and Montgomery properties, 2 miles northeast of Shell Creek, associated with a gabbroitic rock in an area of granite which is mapped by Keith as Beach granite. Specimens of this have been found by Dr. Hinds to contain 8.00 per cent of titanium dioxide.

Although very little has been learned about the Tennessee titaniferous ores, it appears probable that they are in every respect like similar ores in North Carolina and that their origin is the same. At present they are of no economic importance.

DEPOSITS IN THE PIEDMONT AREA.

In Caldwell, Rockingham, Guilford, and Davidson counties, in the western part of the Piedmont area in North Carolina, there are a number of deposits of titaniferous iron ore, some of which contributed comparatively large supplies to the old forges. At Richlands Cove, on Yadkin River 16 miles north of Lenoir, is a compact, slightly magnetic ore body 45 feet thick, distributed through a talcose chlorite schist.[45] A sample of the pure ore gave the following result:

Partial analysis of ore from Richlands Cove, N. C.

Silica (SiO_2)	7.55	Phosphorus (P)	1.40
Iron (Fe)	28.24	Titanium dioxide (TiO_2)	41.21
Sulphur (S)	.013		

indicating an excess of titanium dioxide over the amount necessary to combine with all the iron to make ilmenite.

Singewald[46] says that the ore consists chiefly of small particles of ilmenite in a matrix made up mainly of fibrous and scaly aggregates of chlorite, serpentine, and talc, but Hess,[47] in 1906, had noted that it contains magnetite, ilmenite, and rutile.

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[45] Nitze, H. B. C., op. cit., p. 120.

[46] Singewald, J. T., jr., The titaniferous iron ores in the United States: U. S. Bur. of Mines Bull. 64, p. 84, 1913.

The largest zone[48] of titaniferous magnetites in the State extends from the headwaters of Abbots Creek, in Davidson County, across the southwest corner of Forsyth County and entirely across Guilford County to Haw River, in Rockingham County, a distance of 30 miles. It consists of two parallel belts 3 miles apart throughout their greatest distance but approaching until, as believed, they unite in Rockingham County. The ore bodies consist of strings of lens-shaped masses, continually enlarging and contracting in thickness, from a few inches to 8 feet. Some of the ores contain granular corundum, in one or two places in so great quantities that they become true emery. Lesley thought that the ore-bearing layers were deposited at the same time as the rocks that hold them, as they differ from the other rocks of the series only in being more highly charged with iron. The ore beds vary in number at different places and are irregular in position in the nonferriferous rocks, but Singewald,[49] who visited the Guilford County deposits in connection with his work on the utilization of the titaniferous magnetites, found that the ore bodies are segregations within small gabbro masses. At the Tuscarora mine, he says, the rock immediately associated with the ore is an olivine gabbro with a diabasic texture, and the gangue of the ore is a mass of chlorite and small quantities of material so greatly decomposed as to make it undeterminable.

The Tuscarora mine, 1 mile north of Friendship, was the principal opening on the southeastern belt. The ore is traceable for a mile in a direction N. 77° E., and the vein has a dip of about 70° a little east of south. There were two ore beds, one 12 feet thick, that were cut by a shaft 109 feet deep.

The Dannemora mine[50] was 20 miles farther northeast. It was in operation as late as 1880 in an ore deposit 125 feet long, 80 feet wide on the incline, and 12 feet thick. Other lenses of approximately the same size were later found to the northwest and southeast of the main one. The ore was accompanied by chlorite and mica.

Analyses of samples taken from several points on the belt are given as follows:

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[47] Hess, F. L., U. S. Geol. Survey Mineral Resources, 1906, p. 530, 1907.

[48] Kerr, W. C., Report of the geological survey of North Carolina, vol. 1, pp. 236–250, 1875. Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, vol. 2, pp. 143–154, 1888. Willis, Bailey, Tenth Census, vol. 15, p. 308, 1886. Nitze, H. B. C., op. cit., pp. 60–68.

[49] Op. cit., pp. 86–87.

[50] Willis, Bailey, Tenth Census, vol. 15, pp. 308–311, 1886.

Analyses of ores from deposits on Tuscarora belt.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	1.31	4.70	0.76	0.40	1.30	12.75	1.30	26.80
Iron (Fe)	55.06	48.31	57.68	59.03	56.41	41.95	67.60	21.63
Alumina (Al_2O_3)	4.26	8.66	1.68	1.06	2.54	5.17	.55	8.87
Sulphur (S)	Tr.	.089	....	....	....	....	....	....
Phosphorus (P)	Tr.	.023	....	....	....	....	....	....
Titanium dioxide (TiO_2)	13.60	13.71	13.52	11.95	12.35	15.35	1.27	16.20
Chromic oxide (Cr_2O_3)	.72	.34	.46	1.07	1.10	1.25	1.43	.43
Manganese oxide (MnO) Cobalt oxide (CoO)	.96	.11	.81	1.02	1.10	1.25	.93	1.55
Magnesia (MgO)	2.33	2.96	2.79	1.99	2.41	4.14	.75	10.30
Lime (CaO)	.60	1.42	.45	.24	.51	.90	.14	1.40
Water (H_2O)	.18	.98	....	.38	.79	1.36	....	3.55

1. Sargent shaft, Tuscarora mine, Guilford County. The iron was reported as Fe_3O_4=76.04. Genth, F. A., Geology of North Carolina, vol. 1, p. 245, 1875.
2. Dannemora mine, Rockingham County. Tenth Census, vol. 15, p. 311, 1886.
3. K. R. Swain's, Davidson County. Iron reported as Fe_3O_4=79.53. Genth, F. A., op. cit., p. 245.
4. Granular ore, Elisha Charles, Guilford County. Iron reported as Fe_3O_4=81.89. Idem.
5. John Clark, Guilford County. Iron reported as Fe_3O_4=77.90. Idem.
6. Soft micaceous ore, Mrs. McCuiston, Guilford County. Iron reported as Fe_3O_4=57.93. Idem.
7. Magnetic portion of No. 6. Iron reported as Fe_3O_4=93.63. Idem.
8. Nonmagnetic portion of No. 6. Iron reported as Fe_3O_4=30.90. Idem.

From a comparison of analyses 6, 7, and 8 it will be seen that as early as 1875 it was learned that most of the titanium dioxide could be eliminated from this ore by careful magnetic cobbing. In 1913 Singewald[51] repeated the experiment more carefully and reached a result that was not quite so satisfactory. His figures are as follows:

Results of cobbing ore from Tuscarora belt.

	Yield of concentrate (per cent).	Fe (per cent).	TiO_2 (per cent).
Ore	....	58.07	12.82
Concentrate, ore crushed to 0.3 millimeter	71.5	67.76	4.25
Tailings, ore crushed to 0.3 millimeter	28.5	33.76	34.32
Concentrate, ore crushed to 0.15 millimeter	70.1	68.41	3.64

A complete analysis of the Dannemora ore was made by the chemists of the Tenth Census.[52] The analysis yielded:

Analysis of Dannemora ore.

Ferric oxide (Fe_2O_3)	43.05	Phosphorus (P)	0.023
Ferrous oxide (FeO)	23.51	Titanium dioxide (TiO_2)	13.71
Sulphur (S)	.089		

If all the ferric oxide is present in magnetite there must also be 19.4 per cent of the ferrous oxide in this component, leaving only 4.1 per cent to supply the chlorite and other ferrous silicates and any ilmenite that might be present.

An insoluble residue constituted 28 per cent of the assay and had the following composition:

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[51] Op. cit., p. 22.

[52] Tenth Census, vol. 15, p. 311, 1886.

Composition of insoluble residue from Dannemora ore.

Silica (SiO_2)	4.70	Soda (Na_2O)	0.05
Alumina (Al_2O_3)	9.75	Phosphorus pentoxide (P_2O_5)	.045
Lime (CaO)	.56	Titanium dioxide (TiO_2)	11.82
Magnesia (MgO)	.72		
Potash (K_2O)	.03		27.675

There was no iron in the insoluble component, consequently almost all the titanium dioxide in the ore must be in the form of an oxide, probably rutile. The large quantity of alumina present may represent corundum, which is known to be associated with the titaniferous ore farther northeast, or some of it may be in spinel, a small amount of which occurs in the Tuscarora ore.

Singewald did not study the ore of the Dannemora mine, but he made a rather thorough metallographic examination of that of the Tuscarora mine, which he stated to consist of about 20 to 40 per cent of ilmenite intergrown with magnetite in plates sufficiently large to be separable by crushing and magnetic concentration.

Examination of thin sections makes it evident that, as in the Dannemora ore, much of the 13.6 per cent of titanium dioxide in the Tuscarora ore must be in the form of rutile, for the sections show the presence of many grains of red-brown rutile embedded in an opaque mineral and to a less extent in interstitial light-green hornblende between the ore particles. The particles of rutile bear the same relation to the opaque ore, which is presumably magnetite, as the light and dark minerals shown in Singewald's photographic illustration of a polished specimen of the ore.[53] The rutile in the ore occupies the position corresponding to the light portions of the illustration. It usually occurs in streaks about 1 millimeter long and 0.12 millimeter wide, or in sharp-edged rhomboidal or wedge-shape grains measuring about 0.7 by 0.3 millimeter in diameter, but occurs also as very irregularly outlined pieces, as narrow rods, and as little dustlike particles scattered irregularly through the magnetite. It is reddish brown, rather strongly pleochroic in yellowish and brown tints, and clouded toward the center with reddish opaque substances that suggest red-stained leucoxene, or perhaps limonite. In the centers of several of the rutile bodies are little masses of a green spinel having very irregular shapes.

Thus the Tuscarora ore resembles very closely the ore of the titaniferous deposits in the mountain district, in all of which most of the titanium dioxide must be in the form of rutile.

On the Shaw belt, which is 3 miles northwest of that on which the Tuscarora and Dannemora mines are situated, three or four distinct and parallel deposits were opened, the widest of which measured 6 feet in width where solid. Some pits on the property were worked in Revolutionary times, but the main openings were made in the seventies. The ore of the Shaw mine contained 14.46 per cent of titanium dioxide.

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[53] Op. cit., pl. 2, C.

One other deposit in Rockingham County is of special interest because of its suggestiveness. Its exact location is not certainly known, and no description of the association of the ore is available. However, two samples from this deposit were analyzed by Genth. One was a granular reddish ore resembling a reddish-brown garnet and the other a grayish granular ore in which minute grains of yellowish or brownish-white corundum were visible.

Analyses of ore from Rockingham County, N. C.

	Reddish ore.	Gray ore.		Reddish ore.	Gray ore.
Silica (SiO_2)	1.39	0.98	Magnesia (MgO)	0.68	3.27
Magnetite(Fe_3O_4)	42.77	46.29	Lime (CaO)	.84	.91
Alumina (Al_2O_3)	52.24	44.86	Titanium dioxide (TiO_2)	.78	2.42
Manganese oxide (MnO) Cobalt oxide (CoO)	1.00	1.27	Chromic oxide (Cr_2O_3)	.30	Tr.

There is no definite statement that the ore is associated directly with basic rocks, but its high content of alumina indicates that it contains so much corundum as to suggest that it may well be genetically related to the corundum-bearing peridotites that have been studied by Pratt and Lewis.[54]

COMPOSITION.

From the descriptions of the ores given in the preceding pages it appears that some of them may be mixtures of magnetite and ilmenite in various proportions. Others are now mixtures of magnetite and rutile, though originally they may have been ilmenite. Some of the ores that are richest in titanium exhibit no magnetism when subjected to the influence of an ordinary horseshoe magnet and may be mixtures of rutile and ilmenite. Singewald[55] has concluded, as the result of his metallographic studies of the titaniferous ores of North Carolina, that some of them are pure ilmenite and others are intergrowths of magnetite and ilmenite. The study of thin sections, however, shows that some of the titaniferous ores contain large quantities of rutile. Singewald[56] has called attention to the fact that Seligman, Cathrein, and Mügge have described intergrowths of rutile in magnetite. Cathrein found the rutile to exist as minute microlites arranged parallel to the three edges of an octahedral face and intersecting one another at angles of 60°, but they were so small that the magnetite appeared wholly homogeneous even when highly magnified, and the microlites were revealed only when the magnetite had been dissolved from the mass by hydrochloric acid. In the few sections of the North Carolina ores that have been examined microscopically the rutile does not occur in minute needles but is for the most part in broad yellowish-brown translucent masses, some of which are wider than the opaque magnetite or ilmenite between them, as if the rutile had formed along definite planes and had gradually replaced the magnetite or ilmenite on both sides,[57] until in some places only a narrow layer of the opaque mineral is now left between neighboring layers of the brownish rutile. That the opaque mineral is magnetite rather than ilmenite is indicated by the strong magnetism of the ore. It is possible that the material of the ore grains was once an intergrowth of magnetite and ilmenite and that the present interlayering of magnetite and rutile is the result of some sort of metamorphism of the ilmenite.

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[54] Pratt, J. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, 1905.

[55] Singewald, J. T., jr., The titaniferous iron ores in the United States: U. S. Bur. Mines Bull. 64, pp. 80–93, 1913.

[56] Op. cit., pp. 24, 27.

In the Tuscarora ore, however, the rutile is apparently original, as many of its particles, which are completely embedded in the ore minerals, show crystal outlines.[58] Moreover, in a few places similar crystals are embedded in the amphibole that lies between the ore grains. It seems necessary to conclude that this rutile was one of the first minerals to solidify, being preceded only by the spinel that occupies the centers of many of its grains.

Chromic oxide has been found in all the titaniferous ores of the district studied whenever it has been sought in the analyses. On the other hand, it is absent from ore containing only small quantities of titanium. In the titaniferous ores the chromium is evidently in the magnetite rather than in distinct particles of chromite, for when a specimen of ore from the Tuscarora belt was subjected to the influence of a magnet most of the chromium went with the magnetic portion.

After Kemp[59] had studied the Adirondack ores he concluded that vanadium is a characteristic component of the titaniferous magnetites, and that these are the only varieties that contain more than a trace of this metal. In view of this conclusion it is interesting to note that none of the titaniferous magnetites in either North Carolina or Tennessee, so far as is known, contain even a trace of vanadium. In three analyses vanadium was sought with negative results.

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[57] The appearance is very similar to that of the polished surface of the Tuscarora ore illustrated by Singewald (op. cit., pl. 7, A), who describes the light-colored bars as ilmenite.

[58] Since this statement was written Mr. Hess has called the attention of the writer to a crystal of rutile from Shooting Creek, in Clay County, that is an intergrowth of a large proportion of rutile and a small proportion of ilmenite.

[59] Kemp, J. F., The titaniferous iron ores of the Adirondacks: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 390, 1899.

The high alumina shown in many of the analyses may be due in some of the ores to corundum and in others to spinel.

ORIGIN.

From a consideration of the scanty facts known concerning the association of the titaniferous ores, it seems probable that their origin is due to the presence of dikes and lenses of olivine gabbro or more basic rocks (dunite and peridotite) in the schist. Only at Senia, on Roaring Creek (p. 253), is there direct evidence of the existence of dunite with the ores, but at several of the old mines the ores are associated with certain talcose, chloritic, and serpentinous schists that may have been derived from olivine rocks, and at one place the rock immediately associated with the ore is an olivine gabbro or a hornblende schist that may well be a metamorphosed gabbro.

The universal presence of notable quantities of chromium in the titaniferous ores and the absence of this metal from the nontitaniferous magnetites indicate a difference in origin. This is further indicated by the universal presence of epidote in the nontitaniferous ores and its absence from the titaniferous ores. The nontitaniferous ores are plainly related to pegmatites. The titaniferous ores are not so related, or at any rate pegmatites have not been found with them. The titaniferous ores appear to be associated with basic rocks, which elsewhere in the State comprise dunite, amphibolite, and olivine gabbro.[60] These peridotitic rocks when well developed contain corundum, spinel, chromite, and in some places rutile.[61] The ores always contain titanium, chromium, and spinel and are in some places associated with corundum (p. 255). It appears probable that the titaniferous magnetites are connected genetically with apophyses from the dunite and peridotite magmas that have intruded the schists along their foliation planes in the form of narrow veins or flat lenses. The ore veins are portions of these rocks rich in ferruginous material. The ores correspond in this respect to ores of the same kind that are associated with gabbro in the Adirondacks or with rocks closely related to dunite in Rhode Island and elsewhere and that have been generally regarded as magmatic segregations. In North Carolina, however, some of the ores are apparently in distinct dikes or in parallel-walled veins, and these may have been deposited by hydrothermal processes. At Senia the ore is distinctly later than the dunite in which it occurs, and in the sections of the Smith and Pennington ores the ore minerals are younger than the silicates associated with them. Consequently they can not have been deposited by segregation from a magma the greater portion of which was still liquid but must have been intruded between the solidified components of the magma.

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[60] Pratt, J. H., and Lewis, J. V., North Carolina Geol. Survey, vol. 1, pp. 369–384, 1905.

[61] Idem, pp. 277, 279, 280.

UTILIZATION.

Singewald[62] has shown that for the most part the titanium in titaniferous magnetic ores is due to an intergrowth of some titanium mineral with magnetite so intimate that their separation is not practicable on a commercial scale. In North Carolina only the ores of the Tuscarora belt might possibly furnish concentrates sufficiently low in titanium to be acceptable to the furnace men to mix with titanium-free ore. But very little is known of the size of the deposits.

No examination was made by Singewald of any of the titaniferous ores of Ashe, Mitchell, and Avery counties, but the study of thin sections of these ores by the writer indicates that their titanium content is due largely to the presence of rutile. This might be separated from the magnetite by magnetic concentration after pulverization, if there were any incentive to make the attempt. However, none of the deposits in any of these counties are large enough to warrant the installation of concentrating machinery so long as the numerous nontitaniferous deposits remain undeveloped.

MAGNETITE-HEMATITE ORES.

DISTRIBUTION AND CHARACTER.

At several localities in North Carolina and in Carter County, Tenn., there are deposits of iron ore that consist of mixtures of magnetite and hematite in widely different proportions. In some deposits the mixture is so nearly pure hematite that it is only weakly attracted by a small magnet. In others the magnet attracts the ore almost as strongly as it attracts the more common magnetites. As most of the deposits are small, they have not received much attention from prospectors.

Nitze[63] refers to several deposits of this kind in Watauga County, N. C., and several near the boundary between Mitchell County, N. C., and Unicoi County, Tenn., but gives no description of their manner of occurrence. He also mentions the fact that the Watauga County belt probably extends into Carter County, Tenn. Martite schists have been described[64] as occurring in the neighborhood of Boone and near the crest of the Blue Ridge as far northeast as the Virginia line. The only specimen seen from any of the occurrences in this belt shows a network of hematite veins forming a zone 2 inches wide in a white fine-grained rock that resembles in general appearance a crushed rhyolite, like the rhyolites associated with the ore at the Finney & Teegarden mine, near Lunsford Branch. (See below.)

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[62] Singewald, J. T., jr., U. S. Bur. Mines Bull. 64, 1913.

[63] Nitze, H. B. C., op. cit., pp. 164–168.

[64] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, Vol. 2, p. 176, Raleigh, 1888.

Reference has also been made in another place (p. 235) to the occurrence of martite with magnetite in ores from deposits in the Piedmont Plateau, but these ores are more closely related to the siliceous magnetites than to the magnetite-hematite ores.

According to Nitze's account a deposit of red specular hematite was uncovered in several small openings on Bald Mountain, near the headwaters of Spring Creek, in Mitchell County. The ore is said to be fine grained and compact, and its wall rock to be "an arenaceous slate striking N. 25° E." Nothing is known of the size of the deposit, but it is stated that the belt of ore has been traced southwestward for 7 miles to Toe River.

The most valuable ores of this type occur near the north border of the area in Watauga and Carter counties that is shown on the maps of the Cranberry and Roan Mountain quadrangles as being underlain by Beech granite, either in the Beech granite or in the Cranberry granite, which adjoins it. (See map, fig. 61.) The Beech granite is characterized by Keith[65] as a white or pink porphyritic biotite granite that is intrusive in the Cranberry granite. It is regarded as the youngest of the Archean rocks of the district but like all the other rocks of this age has been so metamorphosed that it has now become markedly schistose.

Nitze reports a short belt of the magnetite-hematite ores on the south side of Beech Mountain, in the valley of Elk Creek, where it appears as a "bed" between "slaty, gneissoid walls." The ore is very siliceous, and the bed strikes east and dips north. It is believed to be of no commercial value.

Another belt of ores occurs on the southeast side of White Rocks Mountain at the headwaters of Laurel Creek, near the road from Shell Creek to Elk Mills, but nowhere is there any evidence of the presence of large ore bodies, nor are the exposures of such a character as to yield any information in regard to the manner of occurrence of the ore. Specimens appear to be composed almost wholly of magnetite. The only specimen from the locality that has been seen is a titaniferous magnetite containing 8.0 per cent of titanium dioxide. It is reported by Mr. Hamilton[66] to be associated with a gabbro. (See also p. 254.)

Farther down the valley, however, about 5 miles a little south of east of Hampton, on the crest of Keystone Ridge, is the Whitehead prospect, in Cranberry granite. This prospect exposed 4 feet of flinty hematite between a wall of the usual granite and one of a red flinty rock in which only red feldspar and a mixture of magnetite and hematite or martite are visible. Other specimens from this prospect are extremely fine-grained homogeneous steely or flinty blue-gray hematites.

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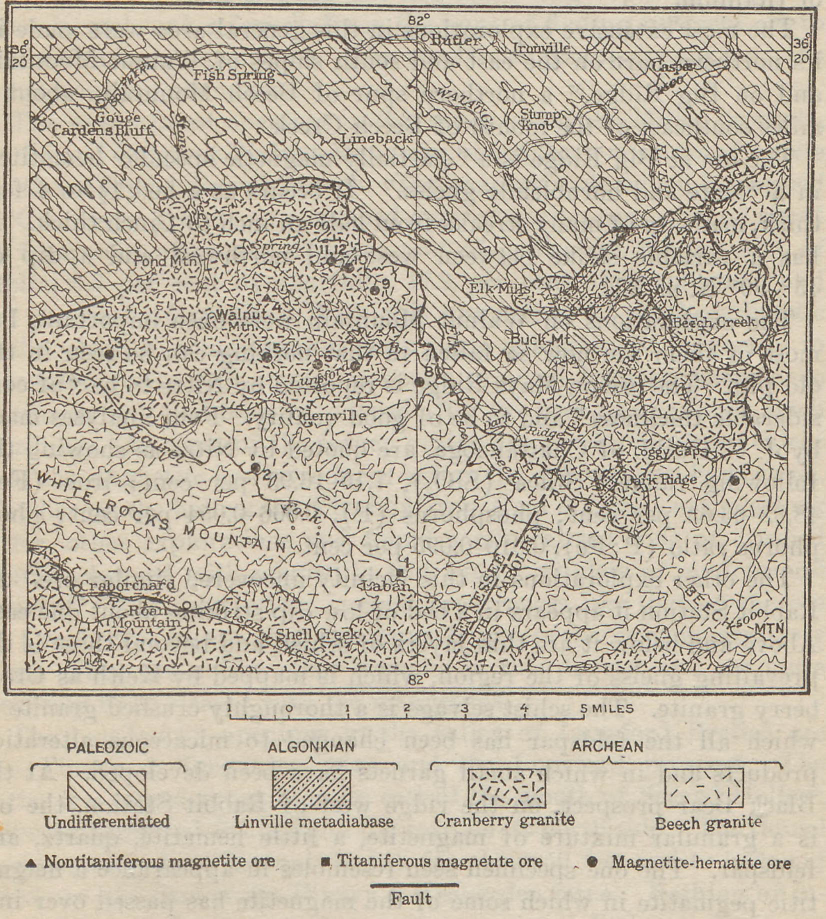
[65] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 3, 1903.

[66] Hamilton, S. H., unpublished report to the Tennessee Geological Survey.


82°
36
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Ironville
Fish Spring
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Cardens Bluff
Lineback
Stump Knob
Caspar
WATAUGA
Pond Mtn
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Walnut Mtn
Elk Mills
Beech Creek
Buck Mt
Lunsford
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Odemville
Dark Ridge
Loggy Gap
13
WHITE ROCKS MOUNTAIN
Craborchard
Roan Mountain
Laban
Wilson
Shell Creek
BEECH 5000 MTN
1 0 1 2 3 4 5 MILES
PALEOZOIC
ALGONKIAN
ARCHEAN
Undifferentiated
Linville metadiabase
Cranberry granite
Beech granite
▲ Nontitaniferous magnetite ore
■ Titaniferous magnetite ore
● Magnetite-hematite ore
Fault

FIGURE 61.—Map showing location of prospects between Shell Creek and Butler, Tenn., and in adjacent portion of North Carolina. (In part after S. H. Hamilton.) 1, Montgomery and Cordell explorations; 2, School House prospect; 3, Keystone Ridge or Whitehead prospect; 4, Miller prospect; 5, Dr. Smith exploration; 6, Finney & Teegarden mine; 7, Lunsford prospect; 8, G. W. Stout exploration; 9, May's Ridge exploration; 10, Rabbit Station; 11, Black Bear prospect; 12, Black's prospect; 13, Big Ridge exploration.

About 6 miles farther east and a little south of the Whitehead place is the School House prospect, where a very small amount of work has shown an ore composed of magnetite and martite crystals and a little interstitial quartz. This ore, according to Mr. Hamilton, from whose notes many of the descriptions of the magnetite-hematite ores are taken, is associated with a dark rock resembling a diorite. A sample of this ore analyzed by Dr. J. I. N. Hinds, of the Tennessee Geological Survey, yielded 62.72 per cent of iron and no phosphorus or titanium.

The most extensive explorations in this general area were made in its northern part on the east and south slopes of Walnut Mountain and on Big Ridge,[67] a northern spur of Beech Mountain, about 2 miles southeast of the mouth of Beech Creek.

The ore at Big Ridge is a "partially magnetic specular hematite" in a "slate and hornblende gneiss." It occurs as a bed 1½ to 4 feet thick, made up of many streaks from half an inch to 1 inch thick. It has a variable strike between west and northwest and a dip of 45°–90° N. or NE.

The explorations on Walnut Mountain were once important, but most of them are now so fallen in that nothing can be seen in the old pits. The ore on Mays Ridge is reported by Nitze to be "of considerable thickness" and to be of good quality. Four analyses made by J. C. Guild, of Chattanooga, are quoted by Nitze as showing the following ranges: Silica (SiO_2), 7.15–16.93 per cent; iron (Fe), 48.82–63.63 per cent; phosphorus (P), 0.006–0.054 per cent; phosphorus ratio (P:Fe), 0.010–0.095 per cent.

The other explorations in this vicinity uncovered similar ore. At Rabbit Station it appears in a bed of low dip striking about due east. Above and below it are thin layers of schist, and beyond these is the prevailing gneiss of the region, which is mapped by Keith as Cranberry granite. The schist selvage is a thoroughly crushed granite in which all the feldspar has been changed to micaceous alteration products and in which small garnets have been developed. At the Black Bear prospect, on the ridge west of Rabbit Station, the ore is a granular mixture of magnetite, a little hematite, quartz, and feldspar. The one specimen seen resembles in appearance a magnetitic pegmatite in which some of the magnetite has passed over into martite.[68]

None of the openings on the east slope of Walnut Mountain are of significance either as indicating deposits of economic importance or as affording opportunities for gaining information as to the origin of the ores. The meager descriptions of the deposits suggest that their ores and their associations at these places are like those of the deposits on Lunsford Branch described beyond and that, in all likelihood, the method of origin in both localities was the same.

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[67] Nitze, H. B. C., op. cit., pp. 165–166.

[68] Specimens of these ores were collected by Mr. Hamilton to illustrate his report to the Tennessee Geological Survey.

Lunsford Branch flows between White Rocks Mountain and Walnut Mountain. At several points in its valley ore deposits are known to occur, more particularly on its south side. Some of these have been explored by trenches and pits, and at two or three places the Virginia Iron, Coal & Coke Co. has made large open cuts, driven tunnels, and sunk a few shafts in the hope of finding sufficient ore to warrant mining operations. The result was disappointing, and the work was soon abandoned.

The westernmost openings in this series are at the Miller prospect, on Scrawl Ridge of Walnut Mountain, about three-quarters of a mile up the valley of Scrawl Branch. The country rock, which is mapped as Cranberry granite, is a crushed quartz syenite, composed of about 20.7 per cent of quartz, 47.1 per cent of orthoclase, 9.8 per cent of albite, 3.9 per cent of anorthite, 17.2 per cent of hornblende, and 1.3 per cent of apatite. With this are masses of crushed dioritic rocks which in some places contain large quantities of magnetite in irregular grains and crystal particles grouped between hornblende grains, as if it had been introduced after the rock had suffered much crushing. As some of the larger grains are fractured, it is evident that the magnetite was introduced before the deformation had ceased. Farther up the hollow the Virginia Iron, Coal & Coke Co. undertook a few other explorations and found a mineralized zone of crushed diorite charged with magnetite and cut by veinlets of epidote and quartz.[69] The descriptions suggest occurrences like that of the ore at Cranberry, except that the deposits are probably comparatively lean. They are unlike other deposits in this district and are more properly to be classed with the magnetites.

The best-known openings in the valley of Lunsford Branch are the Finney & Teegarden mine and the Lunsford prospect. The latter is a tunnel about 1½ miles east of the mouth of Scrawl Hollow, between Lunsford Branch and the road on its north side. The tunnel is reported to have entered the hill for about 50 feet and to have cut good ore like that at the Finney & Teegarden mine. Nothing of interest can now be seen at the prospect except a little ore dump, on which the fragments consist of a slightly banded granular mixture of magnetite, perhaps a little martite, a very little pyrite, and many small round particles of quartz. Their structure is that of a crushed rock into which iron oxides have been forced. According to Keith's mapping the prospect is in the Cranberry granite, but a section on the road just above the tunnel shows a series of parallel layers of much crushed quartz syenite, fine-grained gray rocks, and crushed dioritic rocks. The fine-grained rocks resemble granulitized felsites. Scattered through them are particles of quartz and feldspar a trifle larger than the grains of the matrix in which they lie. This matrix is an extremely fine grained aggregate of quartz, plagioclase, orthoclase, tiny flakes of green hornblende and biotite, granules of epidote, and wisps of muscovite. The constituent grains are elongate in the same direction, and many of them are flattened. The whole mass is silicified so that the original structure is unrecognizable. In the coarse phases the fragmental character of most of the larger components is pronounced. Some of them, however, are crushed into shreds. These phases of the rock are distinctly schistose. The groundmass of all phases is so fine grained and its constituents are so thoroughly crushed that it is impossible to decide whether it is a crushed volcanic rock like a rhyolite or is composed of the débris of a crushed granite or quartz syenite.

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[69] From notes of S. H. Hamilton, in unpublished report to Tennessee Geological Survey.

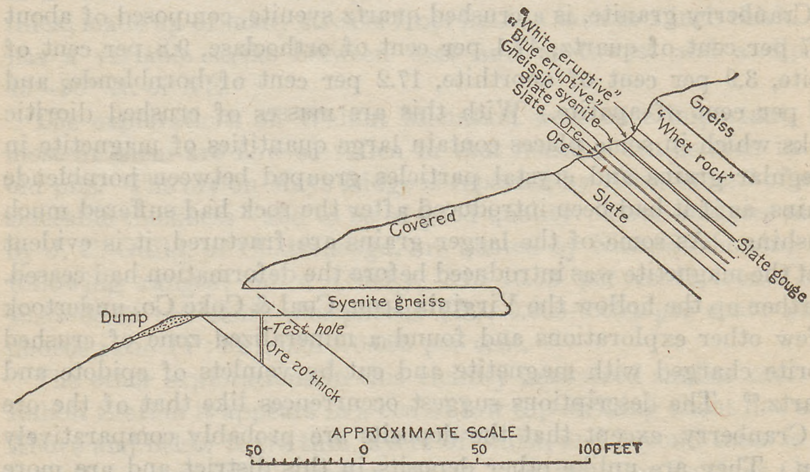

FIGURE 62.—Diagrammatic north-south section through Finney & Teegarden mine, in valley of Lunsford Branch, Carter County, Tenn. (By S. H. Hamilton.)

At the Finney & Teegarden mine the opportunities for studying the relations of the ore to the associated rocks are fairly good. The mine is between the Miller and Lunsford prospects, about 1 mile west of the latter, on the south side of the main stream of Lunsford Branch. In 1912 two open cuts were made here by the Virginia Iron, Coal & Coke Co., a tunnel was driven into the hill from the western cut, and a vertical drill hole was put down at the mouth of the tunnel.

The country rock is a quartz syenite like that at the Miller and Lunsford prospects but very much more thoroughly crushed and therefore more schistose. Interlayered with this is a series of light-gray or white massive and slaty rocks, chlorite schist, and black magnetic ore, striking about S. 60° W. and dipping about 35° SE., into the hill. (See fig. 62.) The chlorite schist is in comparatively narrow layers bordering the ore, the two apparently grading into one another. The ore layers, of which two have been uncovered, are about 5 feet and 30 feet thick, but each is further divided into thinner layers by chlorite-slate sheets a few inches thick. Some of the ore is strongly magnetic, coarsely crystallized, and homogeneous and is broken into cubical masses by joint planes; but most of it is a fine-grained grayish-black mass of irregular grains and minute octahedrons with a very little quartz in the interstices between them. In most of the ore the structure is sugary, with a slight suggestion of banding. In other specimens there is a slight schistosity, and the hand specimens resemble a fine-grained specular ore. In many places through the ore are shear zones marked by chlorite slickensides, and commonly little lenses of chlorite are embedded in it. Where such lenses occur there is usually a slickensided joint extending from the lens.

Analyses by Dr. Hinds of two specimens of the ore from this mine yielded the following results:

Analyses of ore from Finney & Teegarden mine.

	Dump.	"Best ore."		Dump.	"Best ore."
Silica (SiO_2)	13.51	19.94	Soda (Na_2O)	Tr.	....
Alumina (Al_2O_3)	3.52	.24	Potash (K_2O)	0.00	0.00
Magnetite (Fe_3O_4)	82.30	53.13	Phosphorus pentoxide (P_2O_5)	.00	.00
Ferric oxide (Fe_2O_3)	....	26.20	Water (H_2O)	.60	.20
Lime (CaO)	Tr.	.00			
Magnesia (MgO)	Tr.	.00		99.93	99.71

No titanium dioxide was present.

Thin sections of the "best ore" show opaque crystals and groups of crystals in a matrix of small interlocking grains of quartz, in which there are a few small clumps of hornblende or chlorite and a few other fibrous minerals. The quartz grains usually show undulous extinction, and the general arrangement of the ore crystals and groups of crystals is roughly parallel.

The magnetite-chlorite schist on the upper side of the ore is very much slickensided and obscurely layered, like a fine-grained slate. Under the microscope the alternating layers are seen to differ in containing chlorite and fibrous green hornblende. The chlorite layers contain in addition a few grains and crystals of magnetite, a very little interstitial quartz, and a little interstitial fluorite. The chlorite is elongated in a parallel direction, and the particles of magnetite are arranged in lines in the same direction. In the hornblende layers the hornblende forms a meshwork of small fibers. Magnetite is present in much greater amount than in the chlorite layers, and its grains are elongate perpendicular to the layering. The schistosity of these layers is due to lenses of quartz and of colorless fluorite which are arranged parallel to the banding. The rock is apparently a sheared basic igneous rock into which magnetite and fluorite have been injected. According to Mr. Hamilton, a "blue slate" lies 20 feet above the ore. It is like the schist just described but is so thoroughly sheared and slickensided that it is fissile. The slate is thinly banded in dark and light layers; the darker layers are like the chlorite schists that are in contact with the ore, and the lighter layers consist of comparatively large fragments of granulated quartz in a mosaic of finely crushed quartz lenses, separated from one another by thin seams of chlorite or hornblende. Through this mass are thin lenses rich in fibers of a brightly polarizing light-green mineral that may be kaolinite. The rock is so completely crushed and sheared that no hints of its original structure remain.

Between the slaty rocks and the gneissic country rock are layers of white and gray, extremely fine grained rocks that closely resemble in appearance slightly schistose felsites. All of them are imperfectly slickensided, and all are distinctly jointed. Mr. Hamilton has named the three most easily distinguished phases "blue eruptive," "white eruptive," and "whet rock." Analyses of two of these phases show that they are alkali rhyolites. The analysis of the "white rock" was made by Dr. Hinds and that of the "whet rock" by Mr. D. F. Farrar, of the Tennessee Geological Survey.

Analyses of "white eruptive" and "whet rock" from vicinity of Finney & Teegarden mine.

	White rock.	Whet rock.		White rock.	Whet rock.
Silica (SiO_2)	73.78	76.60	Soda (Na_2O)	1.45	4.09
Alumina (Al_2O_3)	13.96	11.98	Potash (K_2O)	5.58	2.20
Ferric oxide (Fe_2O_3)	.80	.27	Phosphorus pentoxide (P_2O_5)	.53	.017
Ferrous oxide (FeO)	1.30	2.72	Water (H_2O) above 100° C	.50	.70
Magnesia (MgO)	....	.36			
Lime (CaO)	2.08	.52		99.98	99.46

The calculated norm of the "white rock" is 39.66 per cent of quartz, 33.36 per cent of orthoclase, 12.58 per cent of albite, 6.95 per cent of anorthite, 2.75 per cent of corundum, 1.72 per cent of hypersthene, 1.34 per cent of apatite, and 1.16 per cent of magnetite—or very nearly like that of some rhyolites. Fluorine was not determined in the specimen of the white rock analyzed by Dr. Hinds, but Mr. Farrar made a special search for it in another specimen from the same locality and found 2.19 per cent.

The least schistose of these rocks is an interlocking aggregate of plagioclase, orthoclase, and quartz grains with average diameters of about 0.4 millimeter forming a matrix around a few larger feldspars that are mainly plagioclase. Tiny masses of fluorite fill the interstices between the grains of the matrix. A few of the fluorite particles are arranged in lines, as if forming tiny veins, but the greater part of the fluorite is distributed uniformly through the section. The only dark components are irregular masses of magnetite that are probably original, as many of them are bordered by small flakes of biotite. The whole section is besprinkled with dust particles which under high powers are resolved into tiny plates of amphibole, glass inclusions, and little colorless prisms too small to be identified. The rock is probably a dike rock closely related to a quartz andesite.

The more schistose layers differ from the rock last mentioned in being much more acidic. Their matrix is very similar, but they contain in addition to large grains of feldspar many large grains of quartz and lenses of quartz mosaic that were once simple quartz grains or perhaps quartz phenocrysts. All the components exhibit the effect of strain. The quartz is granulated, the feldspar is cracked, and the fibrous constituents, which are mainly amphibole, muscovite, or kaolinite, are all arranged with their elongation parallel to that of the quartz lenses. Quartz and feldspars compose the greater part of the matrix, and all the grains appear as if they were crushed fragments. Fluorite is invariably present as a filling of interstices. These rocks might well have been acidic volcanic or dike rocks, like aplites, that have been sheared and later filled with fluorite.

ORIGIN.

There is not much evidence as to the source of the ore layers, but as the iron oxides are closely associated with the chlorite and rhyolitic layers, and as the ore and chloritic rock grade into one another, it is reasonable to suppose that the ore and layered rocks are genetically connected. The general occurrence of fluorite in the layered rocks suggests the presence of an emanation of fluorine or fluorides from a subterranean magma. This emanation may have risen after the intrusion of the rhyolite and andesite into the country rock, and it may have been accompanied or immediately preceded by intrusions of more basic material than the earlier ones, giving rise to what are now the chlorite schists and the "blue slates." With these came the iron oxides in the form of magnetite, some of which was later changed to martite, or it is even conceivable that some of the oxides were magnetite and others hematite, as in a few places hematite alone is known to occur in veins cutting the schistose country rock. Clarke[70] calls attention to the fact that ferric oxide can crystallize from magmas as hematite only where ferrous compounds are either absent or present in very subordinate amounts, for ferrous oxide unites with ferric oxide to form magnetite. Magnetite therefore appears more commonly in rocks rich in ferromagnesian minerals, and hematite appears chiefly in more acidic, alkaline rocks like rhyolites and andesites. It is possible that in the deposits here considered the proportion of ferrous oxide in the product of the emanations was influenced in some way by the presence of fluorine or fluorides in the magma, because at Cranberry and other places in the mountains there is no evidence that the magmas that produced the pegmatites, which are also acidic, contained fluorine, and the iron is in the form of magnetite.

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[70] Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, p. 342, 1920.

Because the associations of the more common magnetites, like those at Cranberry, are different from those at the Finney & Teegarden mine, it is inferred that the sources of the two kinds of ore were different. Both are thought to be of magmatic origin, but the Cranberry ore is believed to have been brought into its present position by pegmatites and the emanations accompanying them, and the ore of the Finney & Teegarden mine to have been brought up by basic phases of the magmas, the earlier intrusions of which were the rhyolites. The advent of the magmas was followed by emanations of iron compounds and fluorite. In both localities the intrusions followed zones of weakness in the country rock, and in both the intrusive masses were folded with the country rock by later deformation.

RESERVES.

There is very little evidence upon which to base an assertion as to the economic value of the magnetite-hematite ore. Most of the deposits seen are too small to warrant consideration as sources of ore. Those on the belt in the valley of Lunsford Branch are the largest known, but they are so inconveniently situated with respect to transportation that it will be a long time before they can be worked profitably. So far as can now be judged, without a great deal of additional exploration, the quantity of ore in the belt is not sufficient to warrant the building of a branch from the railroads at Butler or Shell Creek. The ore is of good quality, but it is not likely that more than 65,000 tons of merchantable grade will be available within 500 feet of the surface for each 1,000 feet of the length of the belt.

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